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I/J BAND LOW-COST CROSSED-FIELD AMPLIFIER.(U)

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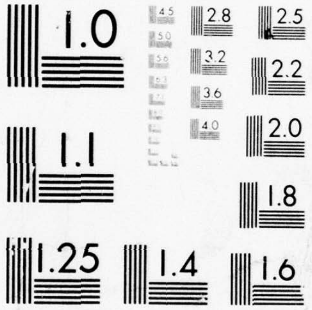
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Research and Development Technical Report

ECOM- 77-2642-1

I/J BAND LOW-COST CROSSED-FIELD AMPLIFIER

Robert R. Moats
Northrop Defense Systems Division
Electron Tube Section
175 W. Oakton Street
Des Plaines, Illinois 60018

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The effort in this program is directed toward the development of an I/J band linear format injected-beam crossed-field amplifier (IBCFA) for electronic warfare, capable of power output of 1000 W peak, 200 W average, between 8.5 and 17 GHz with 20 dB gain. A laser-cut shaped-substrate meander line will be used. Performance in an E/F band IBCFA will be evaluated, for →

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which the objective performance is 3.0 kW peak power output, 1.0 kW average power output in the 2-4 GHz band, also with 20 dB gain. In addition, a gun for I/J band is to be designed and evaluated.

The most important part of this program is the development of technology of the combination of meander line, shaped substrate, and coexpansive ground plane. The shaped substrate concept, including the laser cutting approach, was originated by U.S. Army ERADCOM personnel.

The substrate for the meander line is in a ladder configuration. The electrical properties of the ladder substrate with a meander line have been found to be little different from the meander substrate configuration. The substrate material is beryllia ceramic, which is necessary for good thermal conductivity. Laser cutting the substrates for both E/F band and I/J band has met with limited success to date. The breakage rate is still high, especially for I/J band dimensions.

Copper-tungsten composite material has been evaluated for the coexpansive ground plane. With the proper ratio of tungsten to copper, this material has almost exactly the same thermal coefficient of expansion as the ceramic substrate. Ladder-shaped substrates, metallized by sputtering, have been bonded successfully to the composite material by copper-to-copper diffusion, and the bonding has survived repeated heat cycles to temperatures as high as 700°C.

The metallizing on one side of the substrate must be meander shaped. The most promising approach appears to be to metallize the blank coupon, form the meander shape by photo-etching, and then laser cut.

The E/F band IBCFA design makes use of parts and subassemblies from a previously existing E/F band IBCFA. The copper base structure of the latter tube is mated to the new experimental design by yieldable copper support posts which accommodate the difference in thermal expansion. The gating item in tube assembly is the laser-cut substrates.

A fixture for the I/J band cold-test assembly has been designed and built. The gating item here is also the laser-cut substrates.

Preliminary I/J band gun calculations indicate that only a moderately high peak current density (6.94 A/cm^2) is required, averaged over the emitter surface. If a gridded gun is used, the required peak current density (locally 2 to 3 times as high) can still be achieved easily with dispenser cathodes, and possibly also with "Medicus" nickel-matrix cathodes.

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SECTION I
INTRODUCTION

The effort in this program is directed toward the development of a high-power broadband low-cost I/J band linear format injected-beam crossed-field amplifier (IBCFA) for electronic warfare. A laser-cut shaped-substrate meander line and circuit will be used. Performance in an operating E/F band tube will be evaluated, and a cold-test I/J band meander line will be built and tested. In addition, a gun design for I/J-band extrapolated from the E/F-band device is to be designed and evaluated.

A major cost factor in present IBCFAs is the meander slow-wave structure, which incorporates a meander strip of copper and one separate ceramic insulator supporting each segment of the meander. By replacing the set of insulators with a single shaped substrate which can be manufactured at moderate cost, very substantial cost savings in both time and labor can be achieved. The shaped-substrate concept was originated by U.S. Army ERADCOM personnel, and has been the subject of study by C. Bates and J. Hartley of ERADCOM.

The objective specifications for the E/F band operating model are as follows:

Frequency	2-4 GHz
Peak Power Output	3 kW
Average Power Output	1 kW
Efficiency	35%
Gain	20 dB
Cathode Voltage	7 kV (max)
RF Input Impedance	50 ohms

The cold-test circuit to be built for I/J band is directed toward the achievement of the following objective specifications:

Frequency Range	8.5-17 GHz
Peak Power Output	1 kW
Average Power Output	200 W
Efficiency	30%
Gain	20 dB
Cathode Voltage	8 kV
RF Input Impedance	50 ohms

Ridge waveguide outputs are to be considered for the I/J band circuit.

In a previous program for ERADCOM[1], IBCFAs were designed, built, and tested using simulated shaped-substrate meander lines built with conventional technology. Excellent power and efficiency were demonstrated over an octave band. Peak power was in excess of 3 kW over much of the band with normal RF drive (30-40 W) and beam power (10.5 kW). Power output up to 3.8 kW was achieved with increased RF drive. Efficient operation for 1, 2, and 4 kW outputs was also demonstrated with adjustment of operating parameters.

In this program, actual one-piece shaped substrates are to be used, and one of the major portions of the effort is directed toward the technology of the meander line on such a substrate, and the mounting of line and substrate on a coexpansive ground plane. In other respects, the technology of production IBCFAs will be used as much as possible.

For realization of an E/F band model, it is necessary to develop suitable technology with respect to cutting the shaped substrate from beryllia ceramic, metallizing it, and bonding it to the coexpansive ground plane and to the meander line (if the meander line as a separate part is needed in addition to the metallization pattern). The sequence of these operations has to be determined, e.g., whether the metallization should be performed before or after cutting the ceramic, etc.

The technology of manufacture of the shaped-substrate ceramic is crucial to the successful performance of this project. It is clear that conventional methods of making a single-piece ceramic substrate are inadequate, in terms of both feasibility and cost. ERADCOM personnel have done exploratory work on laser cutting of ceramic substrates in a ladder configuration, and a significant measure of success has been achieved. The configuration of a meander line on a ladder-shaped substrate is shown in figure 1. In previous work performed by Northrop under ERADCOM sponsorship, the difference between the electrical properties of a meander line on a simulated meander-shaped

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[1] Research and Development Technical Report No. ECOM-75-1343-1, Low Cost Crossed-Field Amplifier, Final Technical Report, prepared by Northrop for U.S. Army Electronics Command, June, 1977.

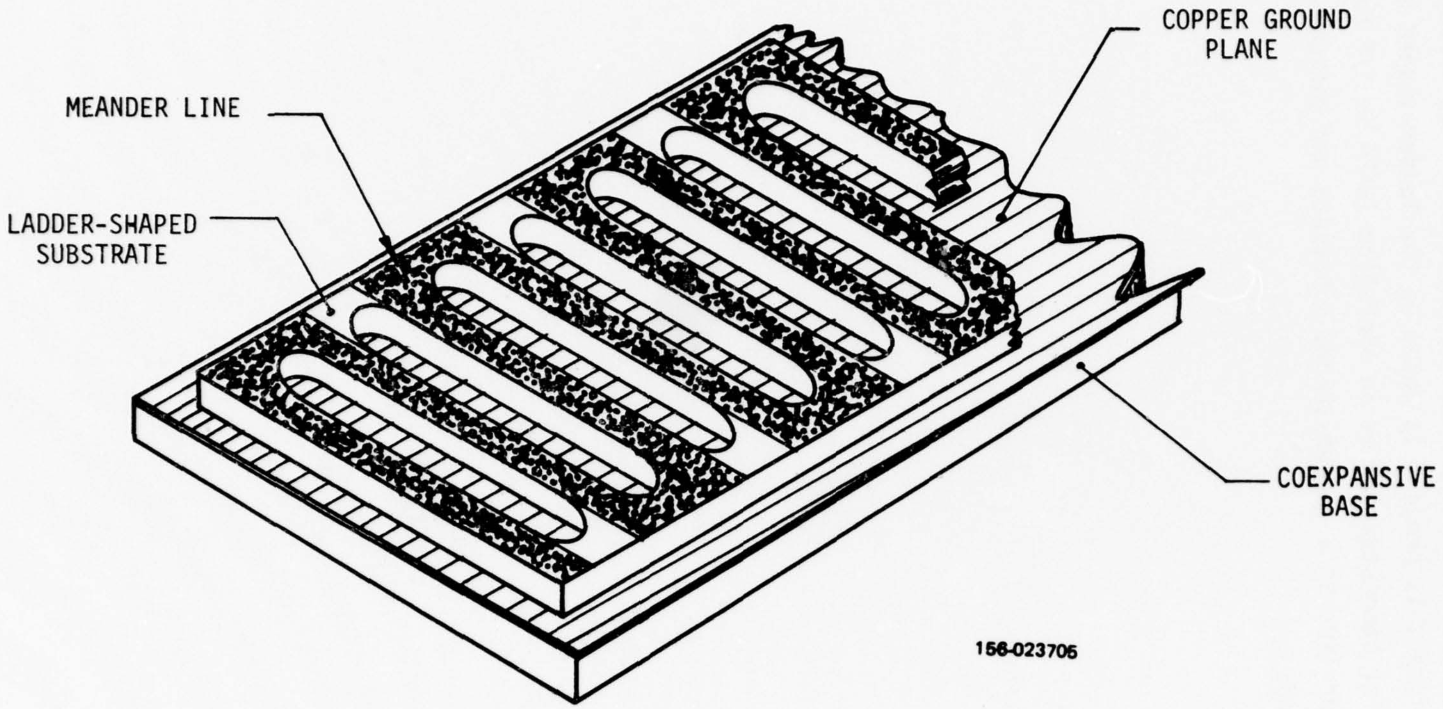

Figure 1. Meander Line on Ladder-Shaped Substrate and Coexpansive Base.

substrate and on a simulated ladder-shaped substrate were found to be insignificant. A meander-shaped substrate is impractical from a mechanical point of view. Therefore this project is based on the ladder-shaped substrate as a starting point for demonstration of an operating IBCFA in E/F band and a cold-test meander line on a ladder-shaped substrate and coexpansive ground plane in I/J band.

SECTION II
TECHNOLOGY

2.1 Bonding to Coexpansive Ground Plane

The first subject considered in the investigation of technology for using ladder-shaped substrates was the coexpansive material for the ground plane. Two different materials have been investigated. The first was beryllia ceramic with metallization applied by sputtering[2,3] so that the copper layer is several skin depths thick to form a good RF ground plane as shown in figure 2(a). The second is a composite material consisting of porous tungsten infiltrated with copper. By a proper choice of the proportion of copper and tungsten, the thermal expansion of the resulting composite material can be made to match the thermal expansion of beryllia ceramic very closely. This is shown in figure 2(b).

One more approach was considered. The ideal material to be coexpansive with a beryllia ceramic substrate is another piece of beryllia ceramic. The disadvantage is that the tensile and shear strength of the ceramic are relatively low, thus complicating the problem of bonding the line and support assembly to the other portions of the tube structure which may not be coexpansive. A "sandwich" consisting of a layer of beryllia ceramic metallized and bonded to a layer of tungsten-copper composite was therefore conceived as shown in figure 2(c). The beryllia would provide a strictly coexpansive layer next to the laser-cut substrate, and the composite material would be brazed to the supporting structure. A possible example of a supporting structure to be used in conjunction with a conventional IBCFA base is shown in figure 3. Cuts are made in the supporting copper piece to form an array of posts which can yield during the braze cycle to take care of the difference in thermal expansion.

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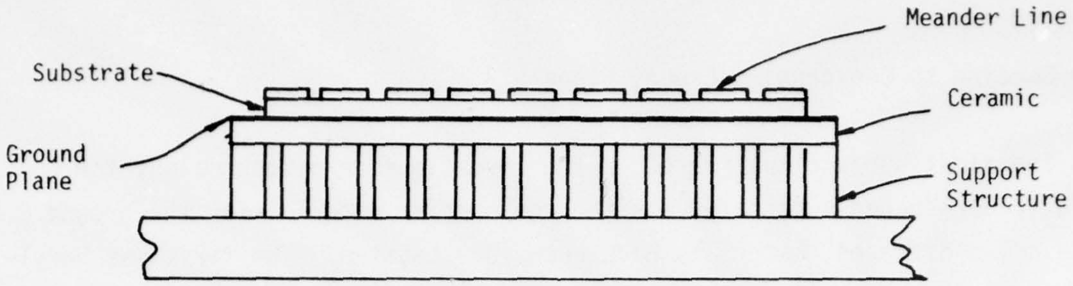
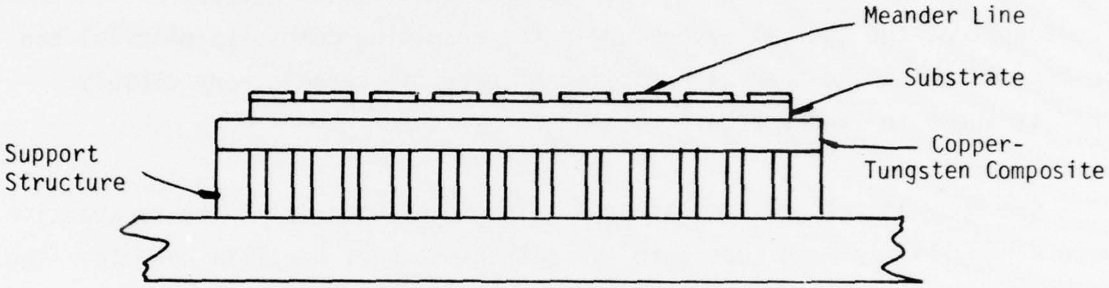
[2] M.L. Cooke, R.R. Moats, "Influence of Metal-Ceramic Bonding Processes in Crossed-Field Amplifier Performance", Conference Record of 1973 Conference on Electron Device Techniques, pp. 76-83, IEEE, New York.

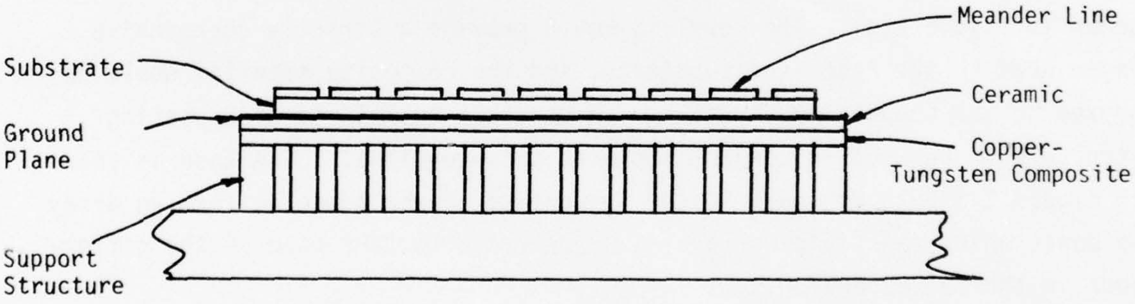
[3] Final Technical Report, <u>Metal-Ceramic Bonding</u>, Report No. AFAL-TR-77-86, prepared by Northrop for U.S. Air Force Avionics Laboratory, May, 1977.



(a) Coexpansive Ground Plane: BeO Ceramic, metallized



(b) Coexpansive Ground Plane: Copper-Tungsten Composite



(c) Coexpansive Ground Plane: Sandwich of Metallized BeO Ceramic and Copper-Tungsten Composite

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Figure 2. Three Possible Configurations for Coexpansive Ground Plane.

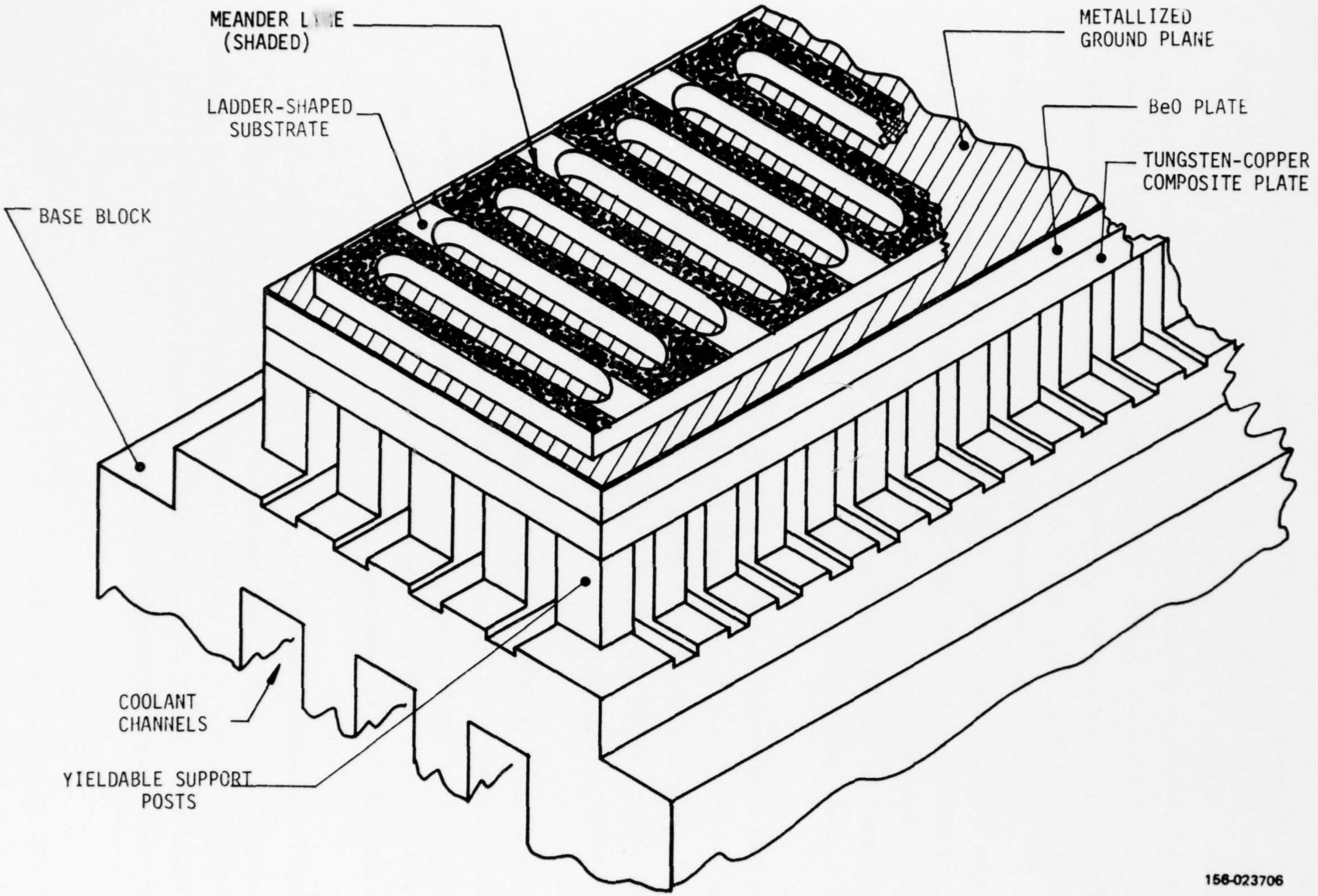

Figure 3. Laser-Cut Ladder Substrate on Coexpansive Ground Plane Supported on a Base Block of Conventional CFA.

The sputter metallization process is preferred to others because of the high tensile strength which has been demonstrated to be consistent[4], the low RF losses[5], and the absence of a glassy interface layer present in other metallizations which introduces a significant thermal barrier. The sputter metallization includes a layer of titanium about 250 Å thick, a layer of molybdenum of 1500 Å or greater thickness, and a layer of copper which is usually a few micrometers thick. The molybdenum, which will not alloy with copper, forms a barrier against copper diffusion into the beryllia ceramic. For I/J band, it is desirable that the thickness of molybdenum should be less than 2000 Å [5], and a nominal value of 1500 Å has been chosen for both the E/F band and the I/J band substrates. Bonding is accomplished by copper-to-copper diffusion under pressure and high temperature (of the order of 1000°C) in hydrogen. The resulting metal-to-ceramic interface has RF losses substantially equal to those of copper alone, and the thermal impedance at the interface is very small.

As to the coexpansive composite material itself, two sources have been used. One material is Elkonite*, and the other material was supplied by Kometco, Inc. The principal difference is that the Kometco material is made using OFHC copper, while the copper in Elkonite is not so specified. In both cases, the material was specified to be 62 percent tungsten by volume.

Samples of both the Kometco material and Elkonite in the form of 1/32-inch-thick plates were tested for vacuum integrity. Both were vacuum tight, as measured on a helium mass-spectrometer leak detector, before firing. After firing at about 1000°C in hydrogen, the Elkonite was porous to helium, while the Kometco material remained vacuum tight.

In the first bonding experiment, a piece of laser-cut ladder-shaped substrate supplied by ERADCOM was sputter metallized and then bonded by copper-to-copper diffusion to a metallized beryllia ceramic coupon. Bonding appeared excellent. After 25 thermal cycles between room temperature and 500°C in hydrogen, no degradation was observed.

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[4] Ibid.

[5] Cooke, Moats. op. cit., pp 76-83.

*Trademark, P.R. Mallory Co.

A similar piece of ladder substrate was bonded to a piece of Elkonite by a similar process. (It has been found necessary to apply a thin layer of copper to the Elkonite before bonding). This assembly was also temperature cycled in hydrogen, 10 times from room temperature to 700°C and return, after which no degradation was observed. As a result of this test, the beryllia support and the "sandwich" approach were put aside, and further work has been directed toward coexpansive ground planes made of copper-tungsten composite.

A piece of ceramic laser-cut substrate (scrap from an ERADCOM order), nearly equivalent to a full length line, was sputter metallized, then diffusion bonded to a supporting piece of Elkonite, which was brazed to a copper base in the form of an array of posts, similar to the arrangement in figure 3, but without beryllia between the substrate and the Elkonite. There was every indication of sound brazing and bonding in all respects. The brazed assembly is shown in figure 4. The assembly was thermal cycled 10 times to 700°C and back to room temperature, with no evident deterioration. Finally, examination of a metallurgical cross section of the ceramic-metal interface showed that the bond was still excellent. (See figure 5.) There was some indication that the Elkonite was bowed or warped. Further tests are to be made to determine whether the distortion of the Elkonite is characteristic of that material, or represents a bi-metal kind of warpage.

2.2 Cutting Substrate and Forming Meander

In making meander lines on ladder substrates, the four operations which must be accomplished, not necessarily in the following order, are:

- Laser-cut slots
- Sputter metallization
- Form meander pattern
- Braze to coexpansive base

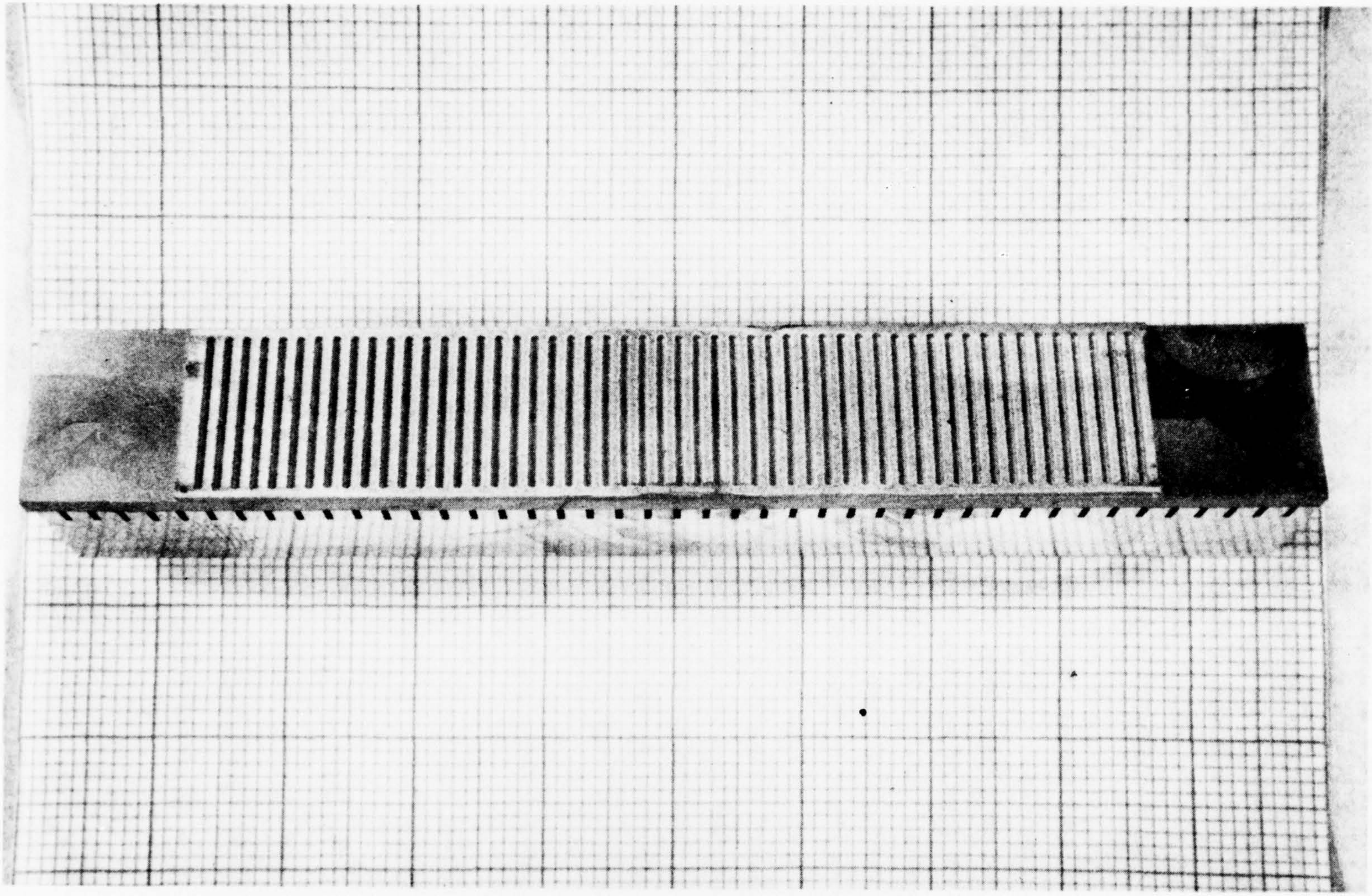

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Figure 4. Mock-up Test of Ladder-Shaped Substrate on a Coexpansive Base and Yieldable Posts.

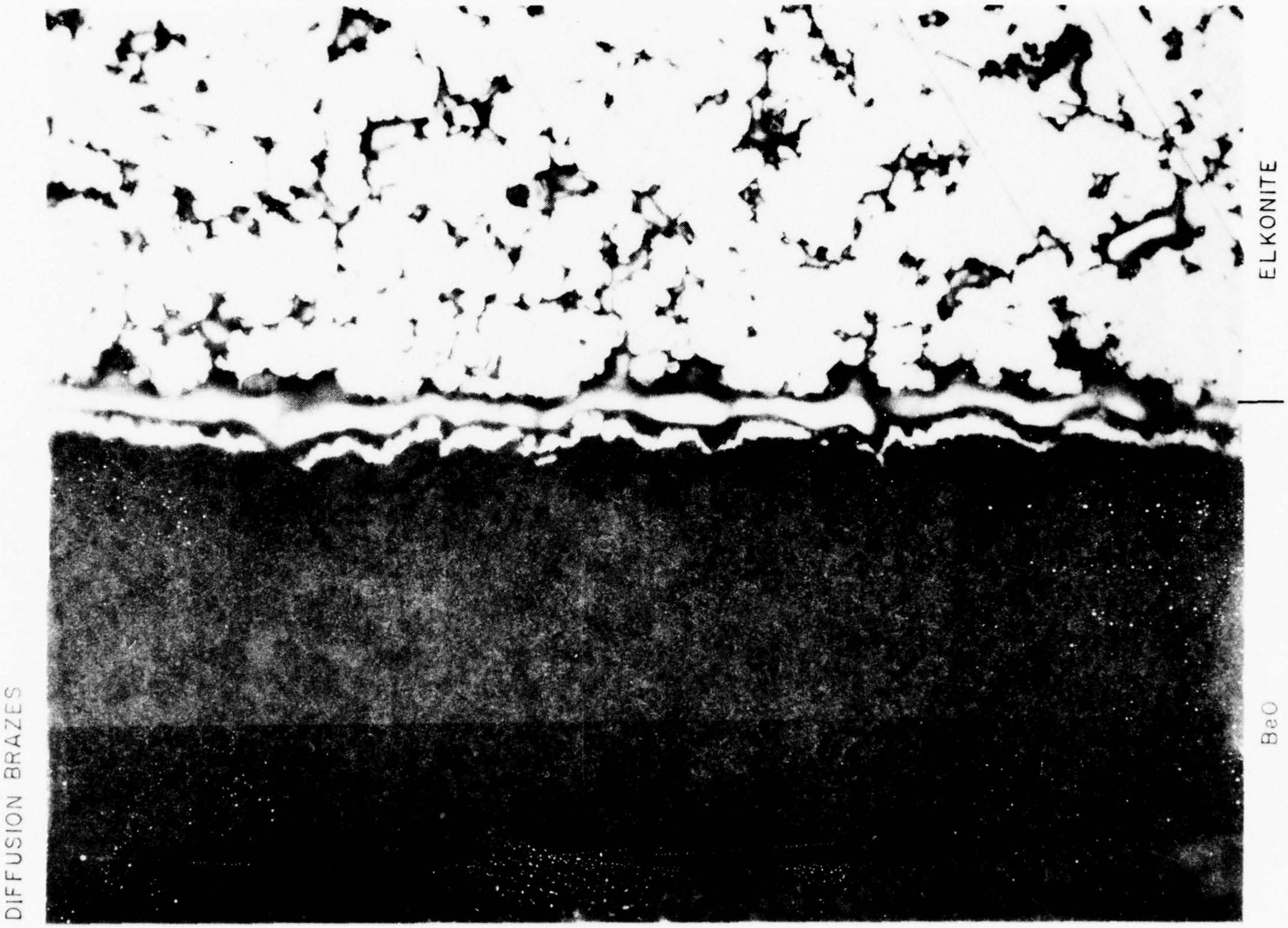

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Figure 5. Metallurgical Cross-Section of Diffusion Braze After Thermal Cycling.

Taking into account the obvious constraints, such as not forming the meander pattern before metallizing (but the meander may be formed at the same time), and brazing only after metallizing, the following sequences appear to be possible:

A. Laser-cut first, followed by:
   1) sputter and form meander, then braze.
   2) sputter, braze, then form meander.

B. Sputter first, followed by:
   1) laser-cut, form meander, braze.
   2) laser-cut, braze, form meander.
   3) form meander, laser-cut, braze (or form meander when sputtering).
   4) braze, form meander, laser-cut.

When sputter metallizing the ceramic ladders after they are laser-cut, it is necessary either to avoid metallization in the grooves and on that part of the top surface which is not to be part of the meander line, or to remove unwanted metallization subsequently. As one approach, individual shields were made by photo-etching, as shown in figure 6. They were found suitable for protecting the slots during the sputtering, but were less satisfactory in shielding that portion of the surface which is not to be part of the meander line. A tighter fit would be necessary. As an alternate, the part of the metallization which is to remain is covered with a photo-resist pattern, and the unwanted metallization removed by etching.

Laser-cutting after sputtering but before forming the meander has been found possible, provided the sputtered layer is quite thin, 1 μm or less. Present experience indicates the layer must be too thin for adequate RF conduction. It will have to be thickened by building up with additional copper. Thickening of a very thin meander shape by electroplating has been found in past work at Northrop to be very nonuniform. A more attractive procedure is to attach a photo-etched meander-shaped layer of copper sheet by brazing.

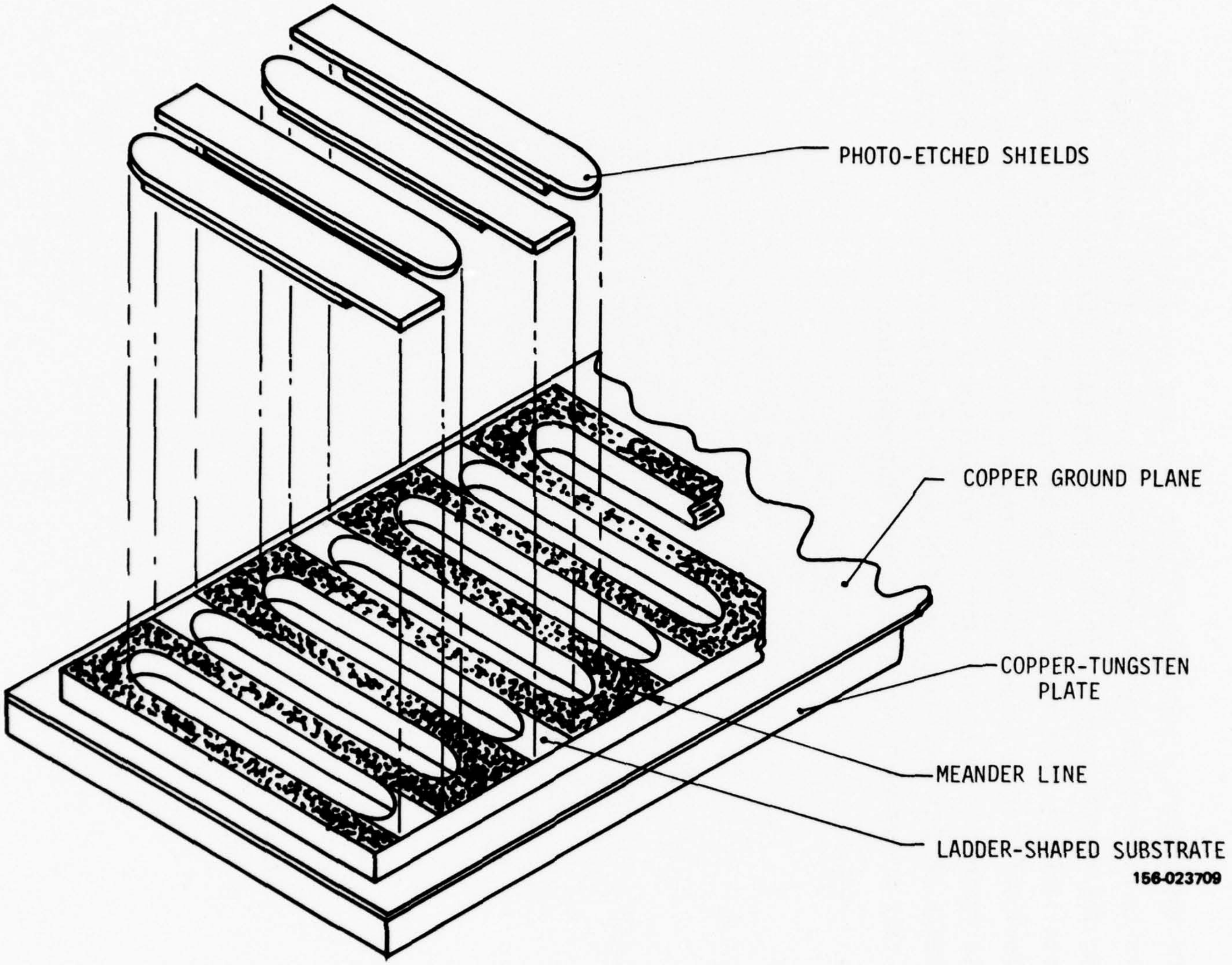

Figure 6. Photo-Etched Shields for Masking During Metallization.

To form the meander during sputtering, appropriate masking is necessary. To form the meander after sputtering, photo-etching appears to be the most feasible process.

Of the sequences previously listed, the most promising at the present appears to be in which the laser-cutting is performed after sputtering and forming the meander, but before brazing to the base. Laser-cutting through the metallizing is thus avoided. Indexing the laser-cutting to conform to the previously formed meander pattern appears easier than indexing an etching mask to conform to laser-cut slots. Samples have been prepared for preliminary tests of this procedure, and substrates for operating E/F band CFAs, in which this procedure is to be used, are in preparation.

SECTION III
E/F BAND IBCFA

3.1 Design of Circuit

The meander line circuit design of the projected operating IBCFA in E/F band was scaled from data supplied by ERADCOM personnel. A substantial saving in program time was thus achieved. These results are shown in figure 7. The line was scaled in wavelength to adjust the frequency corresponding to a 90 degree phase shift per bar from 3.2 to 3.5 GHz. The line width changed from 0.500 inch (ERADCOM) to 0.460 inch, and the pitch would change from 0.050 inch to 0.046 inch for the same delay ratio. The actual value of pitch chosen was 0.048 inch, which has the effect of shifting the delay ratio (c/v_{ph}) from 18.4 at the 90 degree phase-shift frequency to 17.6. The 90 degree phase-shift frequency and the delay ratio thus correspond more nearly to the values used in the simulated shaped-substrate IBCFA[6].

3.2 Mechanical Design

The width of the circuit in the projected tube is comparable with the second design (flat substrate) made during the previous contract, No. DAAB07-75-C-1343 (Reference No. 1), and with a standard E/F band IBCFA. Therefore, a substantial number of parts are common with existing designs. The gun will be similar to that used in the first design (simulated shaped substrate) of the previous contract, except that its width is adjusted accordingly. The base structure is like that of the tubes of the previous contract, except that the coexpansive structure is supported on "posts", as in figure 3.

The input and output connections will be coaxial, and the input and output window seals will be identical to those used on existing IBCFAs. The input and output will be essentially the same for the sake of design simplicity. The coaxial output (or input) will pass through the line support members and connect to the line as shown in figure 8 (cross section) and figure 9 (isometric). The first bar of the substrate must be wider to allow

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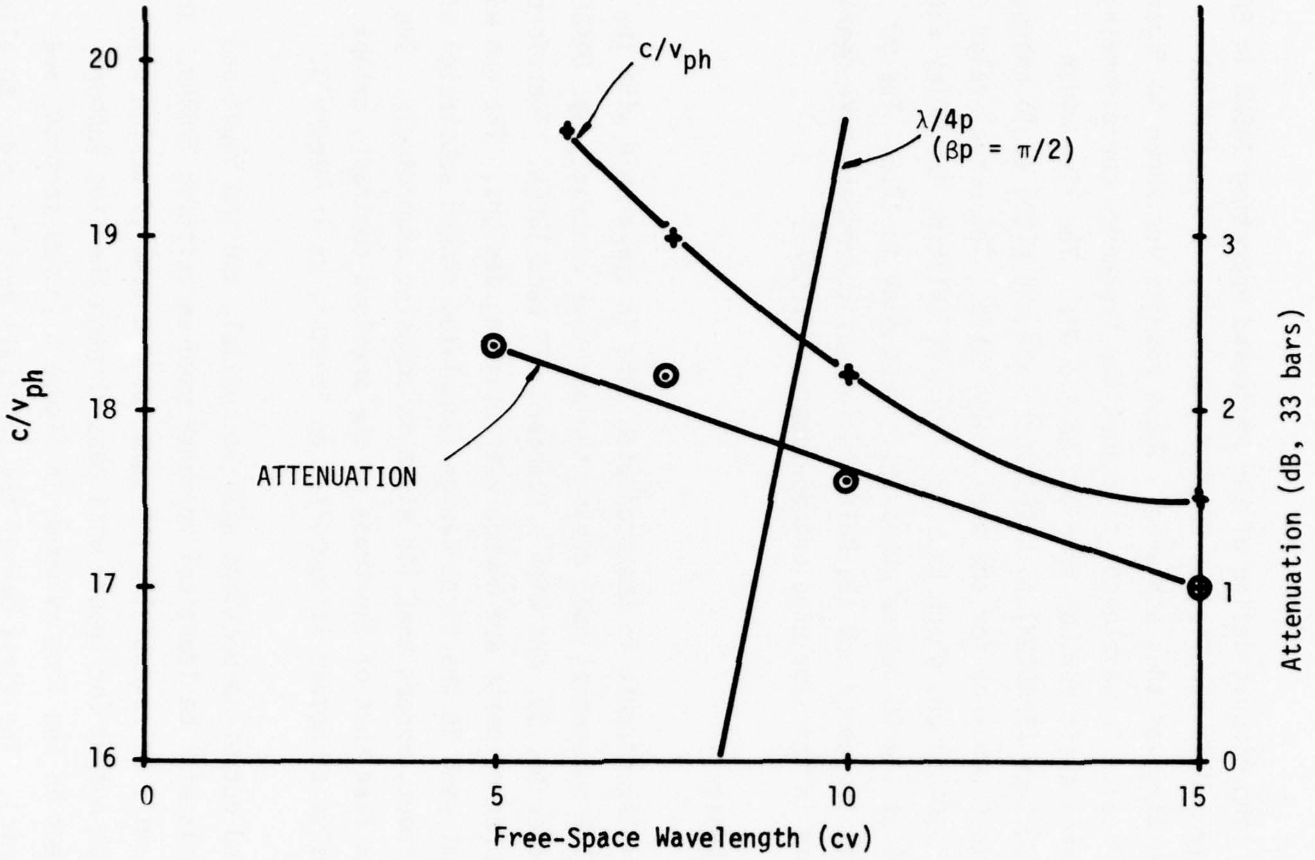
[6] ECOM-75-1345-1, <u>op. cit</u>.



PITCH - 0.050", WIDTH = 0.500", THICKNESS OF SUBSTRATE = 0.017", THICKNESS OF MEANDER = 0.001" (Data supplied by ERADCOM)

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Figure 7. Experimental Results of Meander Line on Ladder-Shaped Beryllia-Ceramic Substrate. (Data supplied by ERADCOM)

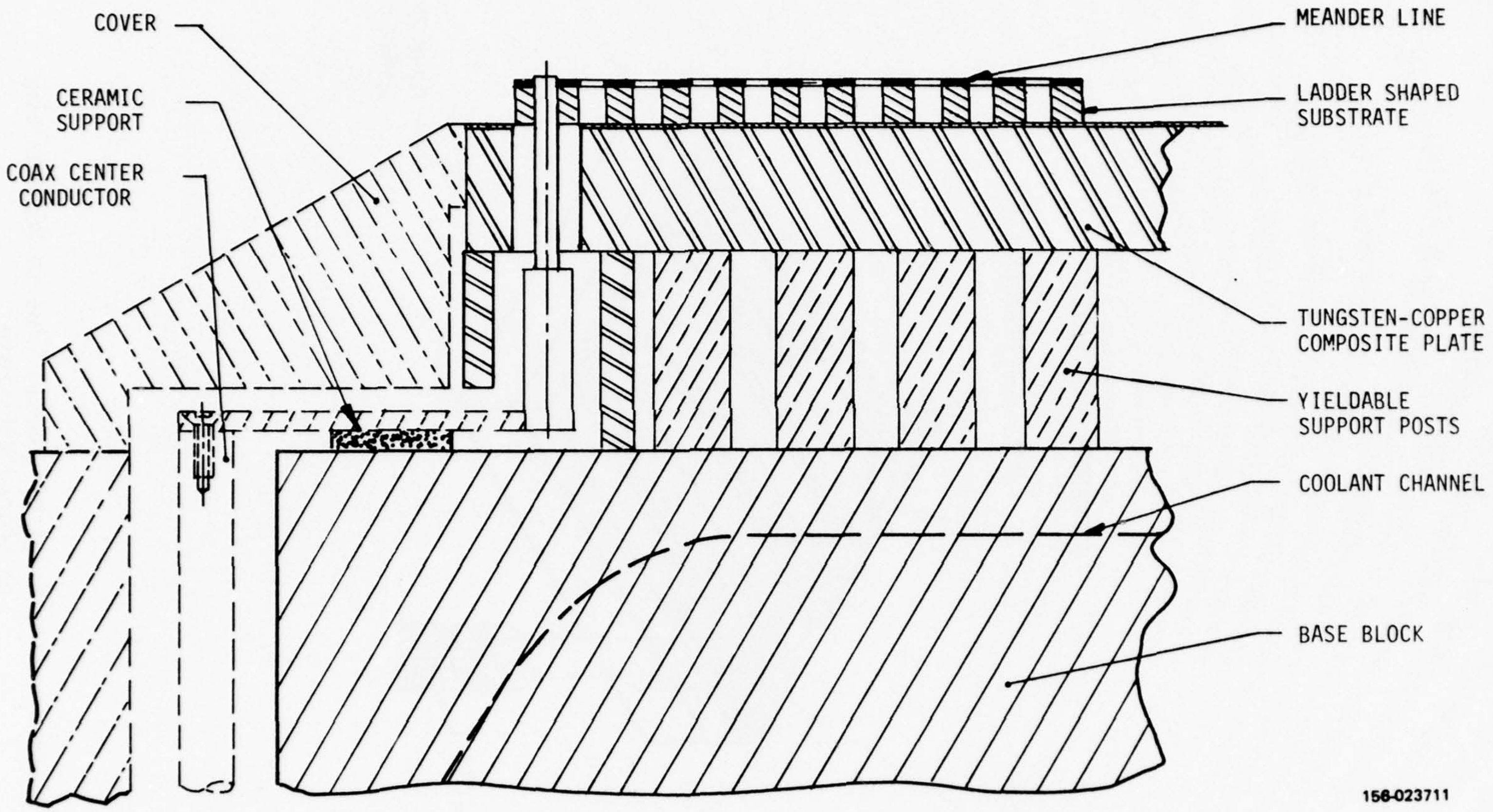

Figure 8. Cross-Section of Attachment of Coaxial Line to Meander Line on Ladder-Shaped Substrate.

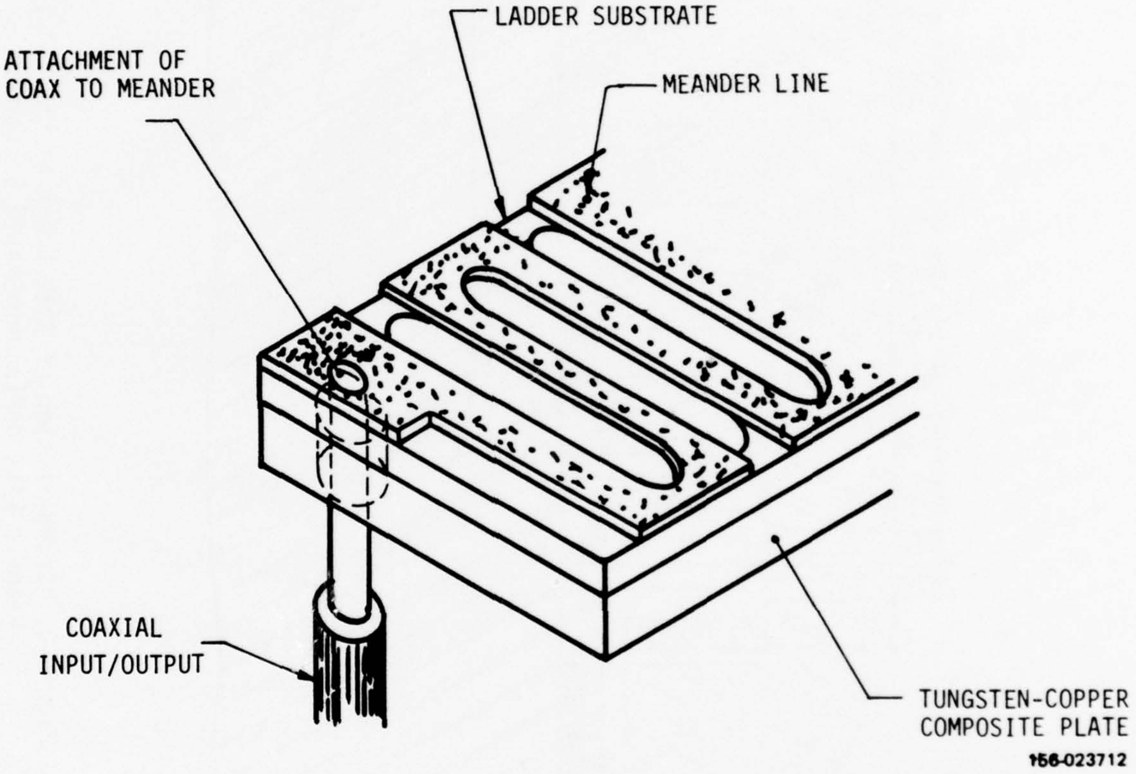

Figure 9. Attachment of Coaxial Line to Meander Line on Shaped Substrate.

a suitable hole through the substrate for the center conductor to be attached. The width of this bar of the meander line may be narrower than the substrate as necessary for RF matching, as shown in figure 9. The metallizing on the meander-line side of the substrate extends through the hole. The opposite side of the substrate must be metallized in a pattern such that there will be no metallization over the coaxial region. The center conductors will be brazed to the hole in the substrate and to the line, if the line is a separate sheet of metal. The center conductors will be copper at this point, and will be hollowed enough at the end to allow flexing during the braze. Their diameter will be about 0.020 inch, assuring adequate output power handling capability, based on experience with existing designs. The two 90 degree bends, as shown in figure 8, allow a little flexing to accommodate thermal expansion, while position is maintained by the ceramic support.

3.3 Parts Procurement and Tube Construction

All of the machined metal parts necessary to start tube construction are available. A few ceramic parts of standard design are still on order, and are not expected to cause delays.

The crucial item is the laser-cut substrates. The first parts to be attempted were cut without metallizing. Because of an error in the tape control of the machine, they were improperly cut. Efforts are being made to salvage them.

The next set of blanks to be laser-cut will be metallized with the meander configuration, and with "cross-hair" locating marks. The meander pattern is presently being etched on substrate blanks.

A number of photo-etched copper meanders have been made, using copper sheets of 0.001 inch, 0.003 inch and 0.005 inch in thickness. The 0.001-inch parts were too thin to hold their shape at all, but the other two thicknesses appear likely to be useful if the best samples are selected.

SECTION IV
I/J BAND

4.1 Circuit

The initial design for a cold-test model of the I/J band circuit is based on the ERADCOM data shown in figure 7. A scale factor of 17/4 in frequency was applied. In addition, the delay ratio was changed from 18.4 to 12. Based on experience at Northrop with IBCFAs in G/H band and above, a lower delay ratio is desired because it leads to larger dimensions, less attenuation on the circuit per wavelength, and lower magnetic field. The lower limit is dictated by electronic efficiency. For 8000 volts cathode-to-line voltage and B/B_{cr} not to be less than one, the delay ratio should not fall below 11.3. A nominal delay ratio of 12 was thus chosen.

The results of the design calculations are as follows:

	ERADCOM DATA	I/J BAND
Frequency Range (GHz)	2-4	8.5-17
Delay Ratio ($\phi=90^\circ$)	18.4	12
Pitch (inch)	0.050	0.018
Bar Width (inch)	0.025	0.009
Slot Length (inch)	0.450	0.106
Substrate Thickness (inch)	0.017	0.006

The thickness of the substrate is chosen to maintain a constant ratio of thickness to bar width. The frequency for 90 degree phase shift per bar is about 13.5 GHz. An alternate design was also conceived with the same dimensions except the thickness, which is 0.009 inch. The latter design will have higher impedance and greater dispersion. Initial work has been started with the substrate thickness of 0.009 inch because of the great fragility of these thin pieces.

Efforts to cut ladders were started with coupons completely metallized with titanium and molybdenum, and with titanium, molybdenum and copper. Considerable breakage was experienced in laser-cutting the pieces metallized with titanium and molybdenum, and even less success was achieved with the pieces which had a layer of copper as well. Much better results were achieved cutting an unmetallized piece 0.010 inch thick. Etching the metallizing to form the meander before laser-cutting, the procedure selected for the E/F band tube, may well be necessary.

Appearance of a laser-cut piece (not a full 50 bars long) was quite ragged in the slots. Bar width was uniform over the 20 bars measured, at 0.0117 inch within a tolerance of about ±0.0001 inch; the specified bar width is 0.0090 ±0.0005 inch. The pitch was uniform and error was noncumulative, the error typically being well within ±0.0002 inch, as compared with ±0.0003 inch specified.

4.2 Gun Consideration

Design of the gun for an I/J band IBCFA depends on interaction space concepts. The interaction space is assumed to be the width of the line, ie, length of the slots in the substrates plus twice the bar width, or 0.124 inch in this case. The line-sole spacing, d, will be assumed to be such that $\beta d=4$ at the high end of the band (where β is the propagation constant corresponding to 17 GHz). For a delay ratio of 12, and for line-to-sole voltage of 12 kV, the line-sole spacing is 0.037 inch, and the magnetic field is 5100 gauss. This value is about twice that used in present 4-8 GHz IBCFAs, which have a delay ratio range of 12.5 to 14. It is therefore appropriate to adopt a cathode dimension in the direction parallel to electron flow about half of that of the 4-8 GHz tube, or 0.090 inch. If peak current up to 0.5 A is required, then the average current density required of the emitter, assumed to be 0.124 by 0.090 inch, is 6.94 A/cm^2.

For a gridded gun, scaling by a factor of 0.5 from the 4-8 GHz tube, the grid to cathode spacing should be about 0.0035 inch, the grid thickness 0.003 inch, the grid bars no more than 0.002 inch wide, and the pitch between center of bars about 0.012 inch. For a beam current of 0.5 A peak, compared with 1.5 A in the 4-8 GHz tube, the dimensions may be a little larger. Further study is needed. With a grid, the local current density needs to be two to three times as much as the average value across the surface. Peak pulse current densities of 20 A/cm^2 are easily achieved with dispenser cathodes, and have been achieved also in some recent samples of "Medicus" nickel matrix cathodes. Therefore, the available cathode emission density is not expected to be a problem.

The gun dimensions calculated are not far different from those used in a J-band IBCFA previously developed at Northrop*, and that experience will be brought to bear on the gun design required here. The only major difference was that the previous gun was designed for a double width line; however, the magnetic field, voltages, and current density were all comparable.

4.3 Ridge Waveguide Output

A possible output configuration to improve power handling capability would use WRD750D24 waveguide, designed to cover the 7.5 to 18 GHz frequency range. A transition from line to single-ridge waveguide is required where the impedance of the single-ridge guide is approximately equal to that of the line, which is expected to be 50 to 60 ohms. From this single-ridge guide, a transition to double-ridge guide along with a transformation to the impedance of the standard double-ridge guide is necessary.

Calculations for a waveguide output transformer have been started. In these calculations, the type WRD750D24 double-ridge waveguide was assumed, for which the low-frequency cut-off is at 6.356 GHz. In the range of 8.5 to 17 GHz, the ratio of guide wavelengths is almost 3:1, and this must be taken into account in the transformer design. An upper limit of 3.5:1 in impedance level ratio between guide and delay line was assumed, based on impedance calculations in the guide (about 175 ohms at midband). Using the work of Cohn[7], it is calculated that the ideal maximum vswr for a system of three quarter-wave transformer sections is 1.15:1; for four quarter-wave transformer sections the ideal maximum vswr is 1.07:1. It is a straight-forward process to establish the initial design of waveguide transformer using the

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[7] S.B. Cohn, "Optimum Design of Stepped Transmission Line Transformers", IRE Transactions on Microwave Theory and Techniques, Vol MTT-3, No. 3, p.16, April, 1955.

*Contract No. F33615-72-C-1356, U.S. Air Force Avionics Laboratory.

procedure described by Hensperger[8]. In addition to the calculations, there is some previous Northrop experience available to be drawn upon in the transition from coaxial to ridge waveguide, including the present E/F band and G/H band IBCFAs, in backward wave oscillators, and in J-band IBCFA which used a transition from line-to-waveguide inside the vacuum envelope.*

An octave-band waveguide vacuum window presents much more difficulty than the impedance transformer. No kind of suitable "thick" window (i.e., thickness of the same order of magnitude as one-half guide wavelength, or greater) is foreseen for an octave band. A "thin" window is necessary. At 17 GHz, a wavelength in beryllium oxide ($\epsilon_r=6.5$) is 0.272 inch. A thin window should be less than one-eighth wavelength (0.034 inch). A value of 0.020 inch thick should be a reasonable starting point, and beryllia ceramics of high quality in this thickness or even thinner are commercially available. Other materials may also be considered. Window sealing technology will be pursued consistent with the broadband output requirements of this device.

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[8] E.S. Hensperger, "Broadband Stepped Transformer from Rectangular to Double-ridge Waveguide", IRE Transactions on Microwave Theory and Techniques, Vol. MTT-6, p.311, July, 1958.

*Contract No. F33615-72-C-1356, U.S. Air Force Avionics Laboratory.

SECTION V
FURTHER WORK TO BE PERFORMED

5.1 Technology

Before any tube construction can start it is necessary to resolve the question as to which sequence to follow in making the line-substrate assembly. First priority is presently directed toward the sequence of metallizing the substrate on both sides, etching out the meander on one side, and then laser-cutting.

An additional problem is assuring the flatness of the assembly after brazing the Elkonite to the support posts. Additional combinations of dummy parts are to be brazed to establish satisfactory design of parts and procedure.

The supplier of laser-cut ceramic substrates still has problems. We plan to supply him with copper heat sinks which are cut to the dimensions of the substrate, except that the copper is dimensioned with 0.002 inch to 0.003 inch relief relative to the parts to be laser-cut (i.e., less copper than ceramic after laser-cutting). Such heat sinks carry heat away from the areas not be cut, while allowing those areas that are cut to be heated more easily.

5.2 E/F Band IBCFA

Two E/F band IBCFAs are to be built and tested. The first measurements will be cold-tests of the circuit to determine delay ratio (c/v_{ph}), characteristic impedance, coupling impedance, and attenuation. The measurements of delay ratio will affect the final dimensions to be chosen for the line-sole spacing and the position of the gun.

5.3 I/J Band

A sample I/J band cold-test line is to be built and tested for delay ratio, characteristic and coupling impedance, and attenuation across the 8.5 to 17 GHz band and a little beyond in both directions. The present problem to be overcome is laser-cutting the substrate.

An elementary gun is to be tested for its basic characteristics. A previous gun design for J-band CFA will be reviewed in finalizing the present design.

A design for a transition from the meander line to double-ridge waveguide will be determined. The design will be based on experience with previous microwave tubes at Northrop.

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[3] Final Technical Report, Metal-Ceramic Bonding, Report No. AFAL-TR-77-86, prepared by Northrop for U.S. Air Force Avionics Laboratory, May, 1977.

[7] S.B. Cohn, "Optimum Design of Stepped Transmission Line Transformers", IRE Transactions on Microwave Theory and Techniques, Vol. MTT-3, No. 3, p.16, April, 1955.

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